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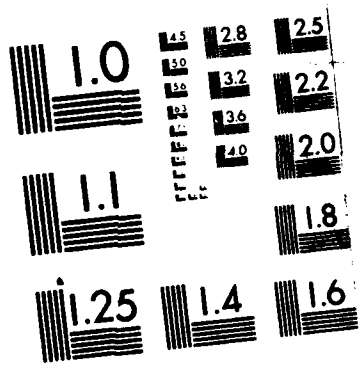
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DYNAMIC PRODUCTION SCHEDULING IN COMPUTER-AIDED FABRICATION OF INTEGRATED CIRCUITS

Christopher Lozinski and Stanley B. Gershwin

Abstract

The scheduling of a VLSI manufacturing facility is being studied using MIT's new Integrated Circuits Laboratory (ICL) as a testbed. This paper describes the facility, outlines the scheduling methodology that is under investigation, and presents the design of the initial preliminary scheduling system.

Microsystems Research Center Room 39-321
Massachusetts Institute of Technology
Cambridge Massachusetts 02139
Telephone (617) 253-8138

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Author Information

Laboratory for Information and Decision Systems, MIT, Cambridge, MA 02139; Lozinski: Room 35-303, (617) 253-2372, Gershwin: Room 35-433, (617) 253-2149.

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by

Christopher Lozinski

and

Stanley B. Gershwin
617-253-2149

Massachusetts Institute of Technology
Laboratory for Information and Decision Systems
Cambridge, Massachusetts 02139

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ABSTRACT

The scheduling of a VLSI manufacturing facility is being studied using MIT's new Integrated Circuits Laboratory (ICL) as a testbed. This paper describes the facility, outlines the scheduling methodology that is under investigation and presents the design of the initial preliminary scheduling system.

INTRODUCTION

Scheduling is the process of allocating the use of a set of scarce resources over time so as to best meet a set of objectives. In this case, the resources are the machines, technicians, and support systems of a semiconductor fabrication facility. The objectives are to satisfy the needs of the users of the facility with minimal delay. Because the resources are finite, there are times when users' needs may conflict. There must be a set of policies to deal with these conflicts, and the scheduler must resolve them in a way that is consistent with system policy.

THE MIT INTEGRATED CIRCUITS LABORATORY

The MIT Integrated Circuits Laboratory (ICL) is a new facility for semiconductor research. It will also serve as both a customer and laboratory for scheduling algorithm development. The building contains offices, clean rooms, laboratory space, and maintenance and support areas. Clean rooms have low particle counts due to constant flow of filtered air. Clean rooms contain either communal or private equipment. Laboratories are not necessarily located in clean rooms.

House systems are threaded through the building providing services such as air flow, humidity control, gaseous nitrogen, deionized water, and solvent waste removal.

A network of computers and terminals provides the hardware needed by the Computer-Aided Fabrication (CAF) project. A goal of this project is the efficient use of computers in semiconductor fabrication. As a part of the CAF project, scheduling is under study for both coordinating the activities in the ICL (to make the best possible use of valuable resources such as machines, technicians, power, steam, chilled water, and chemicals) and to develop algorithms for industry. The purpose of this paper is to describe our preliminary work in scheduling the ICL.

The ICL facility is run by a team of professionals. Technicians maintain and operate equipment. Process engineers are responsible for groups of machines and the processes that run on those machines. A manager is responsible for the smooth operation of the facility.

The facility is used by about 100 students and 20 faculty members whose interests include submicron structures, semiconductor materials, semiconductor devices, semiconductor processes, and CAF research.

Most research involves performing operations on silicon wafers. A group of wafers that is processed together is called a lot. The sequence of activities required to produce a lot is called a flow. A linear sequence of operations is called a linear flow. A flow can branch. Lots can be split for rework or experimentation. The flow of a research lot may also depend on measurements made after a process step. Wafers are discarded if unusable.

In addition to production and laboratory operations, other activities such as maintenance, training, inspection, repair, and machine setups must be scheduled.

PROBLEM DESCRIPTION

The scheduling problem is to choose a vector T where Tj is the time that activity number j is scheduled to begin. Tj is selected from the set of legal times for activity j. This set is limited due to personal schedule constraints, machine repair states, and previously scheduled activities such as preventive maintenance. T is further constrained by limited capacities of machines, house systems, and technicians, and by radio interference among machines and by conflicting setup requirements.

METHODOLOGY

The methodology selected for studying the scheduling of this facility involves the following:

1) Study semiconductor fabrication technology and the ICL to determine important features of the problem. The schedule is constrained by the structure of the system. For example:

a) Exposing wafers to air can dramatically reduce yield. Therefore certain sequences of activities must not have any delay.

b) The house system which supplies deionized water has a 300 gallon storage capacity, and a 30 gallon per minute generation capacity. A single wet sink uses 20 gallons per minute. An effective schedule must limit use of deionized water to within capacity.

c) The ion implanter has two different types of setups. The source and the wafer holder can both be changed. The scheduling system must insure that both setups are appropriate, or it must reserve machine and technician time to change them.

2) Specify objectives of scheduling

Possible scheduling goals include minimizing cycle time (the time a wafer spends in the system), maximizing throughput, minimizing cost, or satisfying a preferred customer. Low cycle time requires small buffers, high throughput requires larger buffers.

Lower costs means things should wait until several batches can be processed together. Satisfying a preferred customer means certain lots move first no matter what the consequences. Each of these objectives can lead to a different schedule.

The initial project goal is to provide a simple, effective scheduling system for the MIT ICL Later versions of the scheduling algorithm will meet criteria such as those described above.

To use optimal control techniques to help develop feedback rules for scheduling requires a numerical objective function L. One possible objective is the minimization of the average expected time between the arrival of an order for a part and the completion of the part.

3) Develop a solution technique.

The scheduling approach will follow the framework described in Gershwin et al. (1986). In that framework, the capacity constraints of the manufacturing system are explicitly modeled and feedback control strategies are developed to respond to random, potentially disruptive events

Because of the complexity of the problem, hierarchical scheduling methods are being developed. The top level of the hierarchy deals with relatively long term issues such as maintenance frequencies, setup frequencies, historical demand, etc. It allocates time on each of the machines for each class of activities. Since there is a substantial setup time between certain activities (such as when there are two different kinds of gases or impurities in a chamber), the frequencies of the changeovers must be chosen with care.

For example, given the best current estimates about usage during a given future time period (such as a week three weeks hence) the top level of the scheduler may decide that the ion implanter will be set up with the hearth stage from 9:00 AM Monday until 11:00 AM Wednesday, after which it will be changed over to the cold stage. Maintenance may then be scheduled until 2:00 PM, followed by a setup with the hearth stage. These allocations are chosen on the basis of historical data, without reference to current requests for that machine during that time period. In addition, some amount of time is built into the setup intervals to allow for such disruptions as machine failures.

As actual demand data arrives, the lowest level of the hierarchical scheduler assigns requests to these time intervals. For example, the period from 9:00 Monday until 11:00 Wednesday of that week is only used to satisfy requests for the ion implanter with the hearth stage. If the demand for the ion implanter with the hearth stage is greater than the allocated time, or if some users have schedule conflicts that prevents their use during that period, the excess is moved to the interval starting at 2:00 Wednesday.

The middle level of the scheduler has two functions: first, it responds to random events such as machine failures. When a machine goes down, it adjusts the schedule in accordance with facility policies about fairly allocating the inconvenience caused by the failure among the users that are affected. Second, it adjusts the setup intervals. If, for example, during some week there is greater than usual demand with the hearth stage and less for the cold stage, the 11:00 Wednesday changeover may be deferred until noon.

If there is a systematic discrepancy between the prescheduled setup intervals and the demand, it is the responsibility of the highest level of the algorithm to adjust the lengths of the intervals.

This preliminary statement is far from complete. We anticipate using methods such as those of Kimemia and Gershwin (1983) and Gershwin, Akella, and Choong (1985) to respond to machine failures, and Graves et al. (1983) and Watts (1986) for the detailed dispatching of lots.

4) Develop an appropriate database.

The detailed schedule is strongly dependent on a wide variety of kinds of information. Required data structures must represent flows, personal schedules, machine schedules, lot schedules, reservations, machine maintenance, machine setup states, machine repair states, the effects of failures of specific house systems, the maintenance of house systems, the priorities of lots, the facilities authorization list, and the skills list.

5) Test the entire system

The scheduling algorithms developed will be used to run the ICL as an experimental test of these ideas.

VERSION 1 SCHEDULING SYSTEM

As a first step towards solving the problem, a simple scheduling system is being implemented. This system is intended to be little more than a computerized sign-up sheet. Its objectives are to

a) Allow users to reserve equipment.

b) Inform users when machines are down, scheduled for maintenance, or reserved by someone else.

The table containing the desired information is shown in Fig 1. There is one column for every resource. The rows correspond to time slots. Future schedules are listed below the current line, previous ones above. The user sees a window into this table as shown in Fig. 2. Because of limited screen size, only four columns, representing four resources, are shown at a time.

CONCLUSION

Scheduling VLSI facilities is a new and important field. Competition is pushing American manufacturers away from mass production and into Application-Specific Integrated Circuits (A.S.I.C.). The rising cost of new facilities is putting pressure to process research lots on the same line as production lots. Both of these trends increase the number of flows in a single facility. More flows make scheduling more difficult and thus increase the opportunity for profiting from scheduling. This will make VLSI scheduling an important activity in the near future.

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